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Experimental Analysis of a Turbo-Charged Common-Rail Diesel Engine Fueled with Biodiesel

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Abstract

In an effort to evaluate the effect of biodiesel fuel on engine performance and emission, experiments are conducted based on a turbo-charged common-rail diesel engine. Results show that the injection timing can be slightly retarded when biodiesel fuel is applied for improved performance and reduced NOx emission. To explain this phenomenon, combustion analysis is conducted based on the cylinder pressure measurement. The shorter ignition delay of biodiesel combustion explains why the best torque timing should be retarded for biodiesel fuel.

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Keyword： Common-rail diesel engine; Biodiesel; Combustion heat release; Injection timing; Torque output; NOx emission

1. Introduction

Biodiesel has been widely used in diesel engines, mainly because biodiesel can be refined form variety of alternative oils such as vegetable oil, animal oil and recycled oil [1]. In addition, it is found in recent studies that the use of biodiesel can reduce CO, HC, PM and CO_2 emissions [2]. However, the automotive application of biodiesel fuel remains a challenging task. Specifically, owing to the lower energy density of biodiesel fuel than that of petrochemical refinery diesel, using biodiesel may cause a decrease in performance and increase in fuel consumption [3]. Moreover, due to the higher oxygen content in biodiesel fuel, it may result in an increase in NOx emission [4]. The common-rail fuel injection systems in modern diesel engines allow further improvement on the performance and reduction of pollutant emissions, noise and fuel consumption [2]. By controlling the common-rail pressure, injection timing and injection pulse width (IPW), the injected fuel amount is precisely metered and the combustion phasing can be optimized [5].

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In this paper, the effect of biodiesel on engine performance and emission is examined based on a turbo-charged common-rail diesel engine. By retarding slightly the injection timing, the biodiesel combustion achieves both improved engine performance and reduced NOx emission. This phenomenon is explained by the combustion analysis conducted based on cylinder pressure measurement.

2. Experimental setup

The experiments are conducted based on a Mitsubishi 4M42-4AT2 commercial truck diesel engine with 2977 c.c. displaced volume and rated power 95 kW at 3200 rpm. Fig. 1 (a) shows a configuration of the experimental engine. The diesel engine is connected to a SCHENCK MP-DYNAS 335 alternative current motor dynamometer, which absorbs a maximum power of 335 kW within 8000 rpm. The engine management system (EMS) is developed based on the MOTOTRON rapid prototyping system. A MPROP valve is used to regulate the common-rail pressure which combined with the IPW command determines the injected fuel amount. The real-time calculation of combustion process is conducted based on the xPC target platform with measurement from an AVL GH13P cylinder pressure sensor and a crankshaft encoder. The engine-out NOx emission is measured by a NGK/Continental Smart NOx Sensor (SNS) with measurement range from 0 ppm to 3012 ppm.

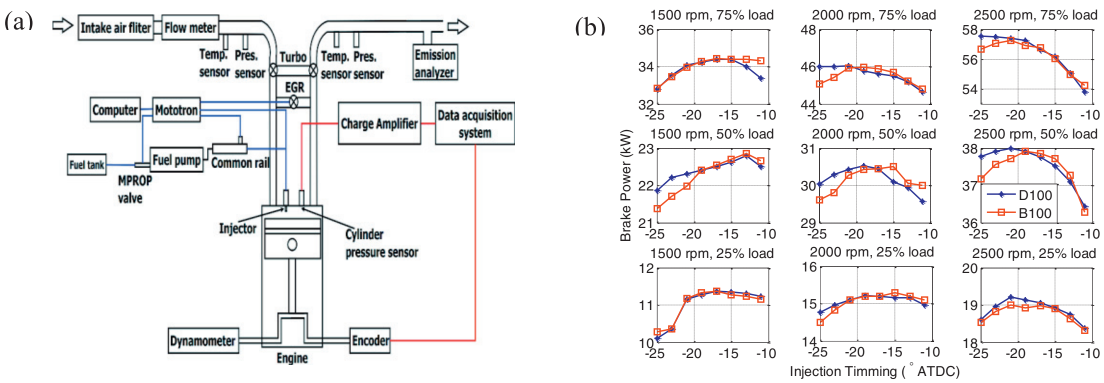

Fig. 1 (a) The diesel engine system and real-time combustion analysis system; (b) Effect of start-of-injection timing on engine brake power at various operating conditions.

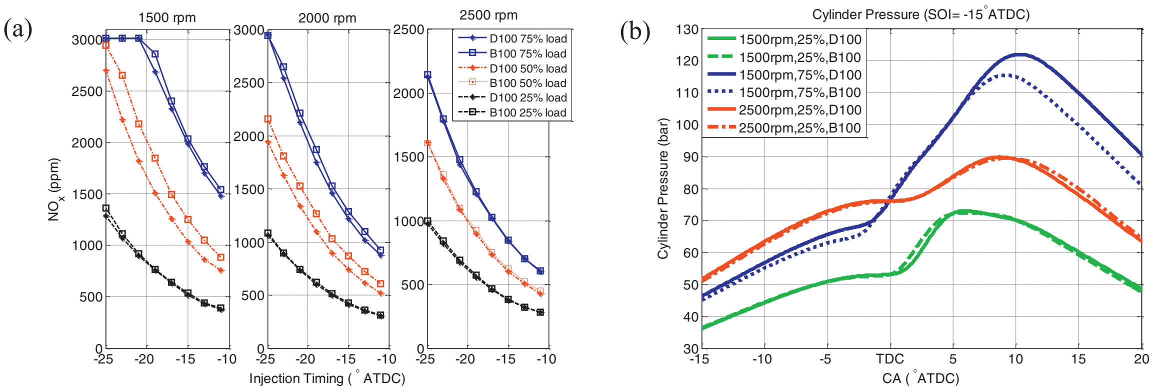

Fig. 2 (a) Effect of the injection timing on engine-out NOx emissions at various operating conditions; (b) Cylinder pressure of the diesel engine with SOI = -15 °ATDC at various operating conditions

3. Experimental analysis

3.1 Optimum injection timing

Control of the fuel injection timing which determines the combustion phasing is key to improved engine performance and reduced exhaust emission. Fig. 1 (b) shows the effect of start-of-injection (SOI) timing on the engine brake power at various operating conditions when pure diesel (D100) and biodiesel (B100) are used. Note that at each operating condition slightly more B100 fuel than D100 fuel (about 10% to 20%) is required in order to generate comparable torque output. Fig. 1 (b) shows that when biodiesel is used the injection timing for best torque output can be slightly retarded, especially at lower engine speed. Fig 2 (a) shows the effect of injection timing on NOx emission at various speed and load condition when D100 and B100 are used. Biodiesel combustion in general produces higher NOx emission than diesel combustion at all the operating conditions. The NOx emission, however, can be significantly reduced by using a retarded injection timing. Therefore, the optimum injection timing for biodiesel can be slightly retarded for both improved torque output and reduced NOx emission.

3.2 Combustion analysis

The heat release phasing is critical to the brake power output of an internal combustion engine. For real-time calculation of the heat release rate (HRR), a simple model is used [6].

$$\dot{Q}_{hr} = \frac{\gamma}{\gamma-1}\cdot \mathrm{P}\cdot\frac{dV}{dt} + \frac{1}{\gamma-1}\cdot \mathrm{V}\cdot\frac{dP}{dt} \tag{1}$$

where Q_{hr} is the released energy, γ is the specific heat ratio, and P and V are the cylinder pressure and volume respectively. In the follows, due to the page limit, only the results at three operating conditions with a fixed SOI timing are demonstrated. Fig 2 (b) shows the cylinder pressure measurement around the combustion top dead centre (TDC) with a fixed SOI timing at -15 °ATDC at 3 operating conditions when D100 and B100 are used. Note again that due to the lower heating value of the biodiesel, about 10% to 18 % more fuel is needed for the biodiesel to generate comparable torque output at each operating condition. The biodiesel combustion renders a slightly lower peak pressure and a slightly advanced pressure-rising timing. Fig. 3 (a) shows the HRR calculated based on the pressure data in Fig. 2 (b). Fig. 3 (a) shows that in terms of crank angle degrees the ignition delay decreases at higher load and increases at higher speed. As the combustion timing is retarded the two-phase combustion becomes less distinct. At each operating condition, the biodiesel combustion results in a slightly shorter ignition delay [6].

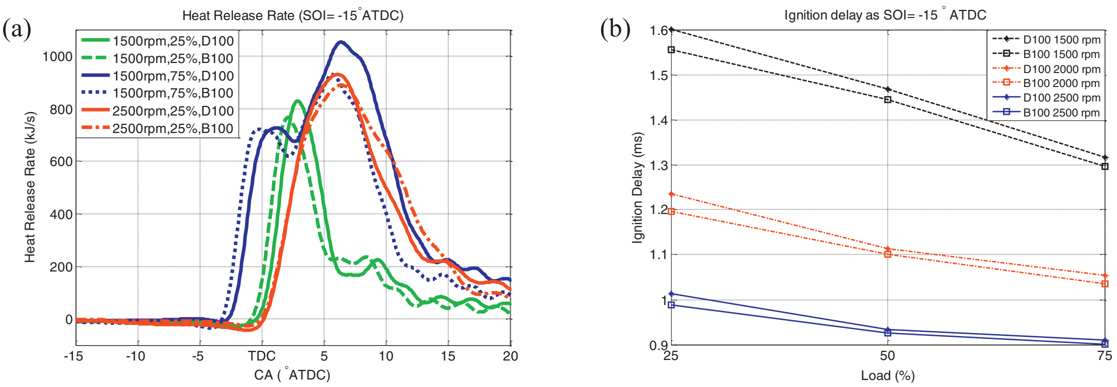

Fig. 3. (a) Heat release rate of the diesel engine with SOI = -15 °ATDC at various operating conditions; (b) Effect of fuel types on ignition delay at various operating conditions

Fig. 3 (b) summaries the ignition delay data with D100 and B100 fuels obtained from the calculation of the HRR at various operating conditions. The ignition delay drops approximately linearly with increasing load. At higher load, temperature of the residual gas and cylinder wall increases and thus results in higher charge temperaure when fuel in injected, which shortens the ignition delay. At higher speed, more fuel is injected and less heat loss occurs during the compression stroke, which in turn shortens the ignition delay. At each operating condition, the biodiesel combustion renders shorter ignition delay than the diesel combustioin. The cetane number of the biodiesel used in this study is 61 while the cetane number of the diesel is 53, obtained from the CPC Corporation in Taiwan. The higher cetain number of biodiesel is characterized by the shorter ignition delay. Note that at lower load the difference of the ignition delay between these two fuels becomes more noticeable.

4. Conclusion

The effect of biodiesel on a turbo-charged common-rail diesel engine is experimentally examined in this paper. For the biodiesel combustion to generate comparable torque to that of diesel about 10% to 20% more biodiesel fuel is needed at each operating condition. Combustion analysis based on cylinder pressure measurement reveals that the ignition delay of biodiesel is shorter than that of diesel fuel due to its higher cetane number. As a result, the injection timing for biodiesel can be slightly retarded while achieving both improved torque output and reduced NOx emission.

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References

[1] United States Environmental Protection Agency, *A Comprehensive Analysis of Biodiesel Impacts on Exhaust Emissions*, EPA420-P-02-001, 2002.

[2] M. Lapuerta, O. Armas, and J. Rondriguez-Fernandez, "Effect of biodiesel fuels on diesel engine emissions," *Progress in Energy and Combustion Science*, vol. 34; 2008, p. 198-223.

[3] W. Yuan, "Computational modeling of NOx emissions from biodiesel combustion based on accurate fuel properties," Ph.D. Thesis, University of Illinois at Urbana-Champaign; 2005.

[4] M. Shahabuddin, A. M. Liaquat, H. H. Masjuki, M .A. Kalam, M. Mofijur, "Ignition delay, combustion and emission characteristics of diesel engine fuelled with biodiesel," *Renewable and Sustainable Energy Reviews*, vol. 21; 2013, p. 623-632.

[5] P. Lino, B. Maione, and A. Rizzo, "Nonlinear modelling and control of a common rail injection system for diesel engines," *Applied Mathematical Modelling*,, vol. 31, 2007, p. 1770–1784.

[6] J. B. Heywood, *Internal Combustion Engine Fundamentals*. McGraw-Hill, NewYork; 1988.

Biography

Chia-Jui Chiang received the Ph.D. degree from the University of Michigan, Ann Arbor, in 2007. Currently, he is an Associate Professor in the Mechanical Engineering Department at the University of National Taiwan University Science and Technology, Taipei, Taiwan. His current research interests include modelling and control of advanced internal combustion engines, energy storage devices, and hybrid energy systems.